

## IMPROVED COMPOSITION AND METHOD FOR REMOVAL OF CARBONYL SULFIDE FROM ACID GAS CONTAINING SAME

The present invention relates to an improved composition for selective removal of carbonyl sulfide (COS) with minimal absorption of carbon dioxide (CO<sub>2</sub>) from an acid gas containing COS and CO<sub>2</sub>, and also to a method for selective removal of COS from an acid gas containing COS and CO<sub>2</sub> using this improved composition.

Natural and synthesis gas streams, derived from natural gas reservoirs, petroleum or coal, often contain a significant amount of carbonyl sulfide (COS) in addition to other impurities such as carbon dioxide (CO<sub>2</sub>), hydrogen sulfide (H<sub>2</sub>S), sulfur dioxide (SO<sub>2</sub>), carbon disulfide (CS<sub>2</sub>), and mercaptans. Various compositions and processes for removal of acid gases, including COS, from a gas containing same are known and described in the literature.

Certain physical solvents have been widely used for the selective removal of H<sub>2</sub>S from gas streams containing H<sub>2</sub>S, CO<sub>2</sub> and optionally, other components. For example, dialkyl ethers of polyalkylene glycols are commonly specified for this purpose. Typical of the numerous disclosures of such solvents in the art is European Patent Application No. EP 0770420 A2 and U.S. Patent Nos. 3,737,392; 3,824,766; 3,837,143; 4,044,100; 4,336,233; 4,581,154; 4,741,745; and 4,946,620, among others. According to such references, it is well known that the solubility of H<sub>2</sub>S in these glycols is much higher than the solubility of CO<sub>2</sub>. This difference in solubility forms the basis for the selective removal of H<sub>2</sub>S by glycol ethers and other physical solvents. Unfortunately, the solubility of COS in most physical solvents is not very different from the solubility of CO<sub>2</sub>. Hence, selective removal of COS or COS and H<sub>2</sub>S from gas streams containing CO<sub>2</sub> and optionally other components, has proved difficult.

Certain tertiary alkanolamines (methyldiethanolamine and triethanolamine for example) have been widely used for the selective removal of H<sub>2</sub>S from gas streams which also contain CO<sub>2</sub>. Users of these amines exploit the rapid reaction with H<sub>2</sub>S and the slow reaction with CO<sub>2</sub> to allow selective removal of H<sub>2</sub>S. Unfortunately, the reaction of these amines with COS is about 100 times slower than the reaction with CO<sub>2</sub>. Hence, tertiary

amines are relatively ineffective at separating COS or COS and H<sub>2</sub>S from CO<sub>2</sub> containing streams.

Certain primary and secondary amines (monoethanolamine, diethanolamine, methylethanolamine, aminoethoxy ethanol, piperazine for example) have been widely used for the simultaneous removal of H<sub>2</sub>S and CO<sub>2</sub>. These amines react rapidly with both H<sub>2</sub>S and CO<sub>2</sub> and are well suited for simultaneous removal of H<sub>2</sub>S and CO<sub>2</sub>. Although the reaction of COS with these amines is also about 100 times slower than the reaction with CO<sub>2</sub>, appreciable amounts of CO<sub>2</sub> and COS can be removed. Unfortunately, since COS reacts much more slowly with these amines than does CO<sub>2</sub>, selective removal of COS or COS and H<sub>2</sub>S with primary or secondary amines has proved difficult.

The selective removal of COS or COS and H<sub>2</sub>S from gas streams containing CO<sub>2</sub> and optionally other components has proved difficult with both physical and chemical solvents. However, in a number of conventional hydrocarbon processing techniques, it is desirable or necessary to remove COS down to few parts per million (ppmv) for several reasons, such as catalyst sensitivity to COS in subsequent operations and statutory or contract requirements regarding sulfur content in product or waste gas streams. The presence of COS has also been identified as the cause of degradation reactions in several commercial processes for acid gas removal. However, in many cases it is neither necessary nor desirable to remove CO<sub>2</sub> from gaseous mixtures.

Various solvent compositions and methods are known for selective removal of COS and H<sub>2</sub>S from gaseous mixtures containing same and other acidic gases such as CO<sub>2</sub>.

25

U.S. Patent No. 3,989,811 (Hill) discloses a multi-step process for removal of acid gases, that is, H<sub>2</sub>S, CO<sub>2</sub>, and sulfur containing compounds including CS<sub>2</sub>, COS, and various mercaptans from sour gases. In this multi-step process, H<sub>2</sub>S, CO<sub>2</sub> and COS are absorbed in a nonselective alkanolamine. The regenerated acid gases are then contacted with a selective amine to produce an H<sub>2</sub>S rich stripper off gas and a low pressure CO<sub>2</sub> rich stream. Suitable alkanolamines include methyldiethanolamine, triethanolamine, or one or more di-propanolamines, such as di-n-propanolamine or diisopropanolamine. The preferred absorbent for treatment of COS containing gas streams also contains a significant amount of

30

a tetramethylene sulfone (the unsubstituted compound is known as sulfolane). In principle, selective removal of COS and H<sub>2</sub>S from the original sour gas stream could be achieved if the CO<sub>2</sub> rich product stream were recompressed and combined with the main treated gas stream. However, the capital and operating costs associated with requiring two absorbers, two strippers and compression of the CO<sub>2</sub> stream would weigh against this option, assuming a less costly alternative can be found.

U.S. Patent No. 4,482,529 (Chen et al.) discloses a single step process for the selective removal of COS from a gas stream containing CO<sub>2</sub>. Small amounts of bicyclo tertiary amine are added to a physical solvent already known to be selective for H<sub>2</sub>S in the presence of CO<sub>2</sub>. According to the invention, addition of the bicyclo tertiary amine encourages hydrolysis of the COS to H<sub>2</sub>S and CO<sub>2</sub>. The net effect is to improve the absorption of COS without substantially increasing the absorption of CO<sub>2</sub>. Applicable physical solvents include SELEXOL<sup>TM</sup> solvent (a blend of polyethylene glycol dimethyl ethers sold by Union Carbide Corporation under the trademark SELEXOL), sulfolane, methanol and others.

U.S. Patent No. 4,524,050 (Chen et al.) discloses a process for hydrolyzing COS in gas streams to H<sub>2</sub>S and CO<sub>2</sub> using solid supported bicyclo tertiary amine catalyst.

U.S. Patent No. 4,504,449 (Doerges et al.) discloses a process for selective removal of H<sub>2</sub>S and possibly COS from a CO<sub>2</sub> containing gas stream using highly volatile secondary amines in an organic solvent. A complex regeneration scheme is required. Applicable secondary amines are diethyl amine, diisopropyl amine, methyl isopropyl amine, ethyl isopropyl amine, dipropyl amine, methyl n-butylamine, methyl isobutyl amine and methyl sec-butyl amine. Applicable organic solvents include alkylated polyethylene glycol ethers, tetrahydrothiophene dioxide etc.

U.S. Patent No. 4,532,116 (Doerges et al.) discloses a process for the removal of H<sub>2</sub>S and/or COS from synthesis gas using at least one secondary amine and an organic solvent. Although the process is selective for H<sub>2</sub>S and COS in the presence of CO<sub>2</sub>, the process is complex. Two scrubbing zones are required – a preliminary desulfurizing zone using a conventional circulated and regenerated solution and a fine desulfurizing or

scrubbing zone using unregenerated solvent. The fine desulfurizing zone contains a heat exchanger to condense the unregenerated solvent. Applicable organic solvents are methanol, ethanol and isopropanol. Applicable secondary amines are N-ethylethaneamine, N-(1-methylethyl)propaneamine, N-methyl-2-propanamine, N-ethyl-2-propanamine, N-propyl-1-propanamine, N-methyl-1-butanamine, N-2-dimethyl-1-propanamine, N-methyl-2-butanamine.

U.S. Patent No. 4,749,555 (Bush) discloses a process for selective removal of H<sub>2</sub>S and COS without absorbing CO<sub>2</sub> from a gas stream having a relatively large concentration of CO<sub>2</sub> using bridgehead amines (bicyclotertiary amine or bicyclo amidine), tertiary amine, physical solvent and water. Applicable physical solvents include sulfolane, polyethylene glycol dimethyl ethers and others.

U.S. Patent No. 4,980,140 (Souby) discloses a process for selective removal of COS from H<sub>2</sub>S using a solvent comprising a tertiary amine, a physical co-solvent and a minor amount of water. The useful physical co-solvent includes sulfones, sulfoxides, glycols and the mono and diethers thereof, 1,3-dioxo heterocyclic compounds (dioxane and dioxolane), aromatic ethers, aromatic hydrocarbons and N-alkylated lactams of gamma or omega amino acids.

U.S. Patent No. 5,413,627 (Landeck et al.) discloses the selective removal of H<sub>2</sub>S and COS from CO<sub>2</sub> using a physical scrubbing agent comprising a heterocycle having five or more ring atoms, which contains two heteroatoms, one of which is nitrogen and the other of which is oxygen or nitrogen. The nitrogen atom present in the ring is/are either double bonded or single bonded but, if single bonded, the nitrogen is organo-substituted. A wide variety of scrubbing agents are disclosed, including 1,3-dimethyl-3,4,5,6-tetrahydro-2(1H)-pyrimidinone (DMTP).

U.S. Patent No. 5,589,149 (Garland et al.) discloses absorption solvents for removing mercaptans from gas streams without the use of iodine. The solvent comprises alkyl ether of a polyalkylene glycol and a secondary monoalkanolamine and, optionally, other amines, such as dialkanolamines.

U.S. Patent No. 6,277,345 B1 (Stankowiak et al.) discloses the use of absorption liquid comprising at least one dialkanolamine, at least one polyalkylene glycol alkyl ether, and water for nonselective removal of CO<sub>2</sub>, H<sub>2</sub>S, COS and other acidic gases from a gaseous stream.

5

U.S. Patent No. 6,102,987 (Gross et al.) discloses a process for removal of CO<sub>2</sub> and sulfur compounds from natural gas and raw synthesis gas with a mixture of N-formylmorpholine and N-acetylmorpholine at temperatures between -20 °C and +40 °C at pressure of 10 to 150 bar in absorbing operation.

10

There is still a need in the industry for an improved composition for selective removal of COS from gaseous streams containing COS and CO<sub>2</sub>. It has now been surprisingly and unforeseeably found out that the addition of a primary alkanolamine, secondary alkanolamine or piperazine compound to a polyalkylene glycol alkyl ether or 1,3-dimethyl-3,4,5,6-tetrahydro-2(1H)-pyrimidinone (DMPT) results in selective removal of COS from the gaseous streams containing same with minimal removal of CO<sub>2</sub>.

15

One aspect of the present invention concerns a solvent composition for removal of COS from a gas stream containing same, said composition comprising

a) at least one polyalkylene glycol alkyl ether of the formula



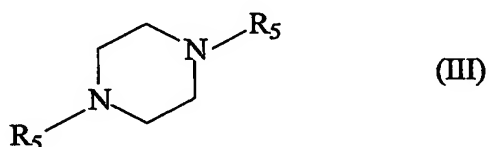
wherein  $R_1$  is an alkyl group having from 1 to 6 carbon atoms;  $R_2$  is hydrogen or an alkyl group having from 1 to 4 carbon atoms; Alk is an alkylene group, branched or unbranched, having from 2 to 4 carbon atoms, and  $n$  is from 1 to 10; and

b) at least one alkanolamine compound of the formula



or

at least one piperazine compound of formula



wherein  $R_3$  is hydrogen, an alkyl group having from 1 to 6 carbon atoms, or the  $R_4OH$  group;  $R_4$  is a branched or unbranched alkylene group having from 1 to 6 carbon atoms;  $R_5$ , independently in each occurrence, is hydrogen or an hydroxyalkyl group having from 1 to 4 carbon atoms; and  $R_6$  is hydrogen, an alkyl group having from 1 to 6 carbon atoms or an hydroxyalkyl group having from 1 to 4 carbon atoms.

Another aspect the present invention concerns a solvent composition for removal of COS from a gas stream containing same, said composition comprising

a) 1,3-dimethyl-3,4,5,6-tetrahydro-2(1H)-pyrimidinone; and

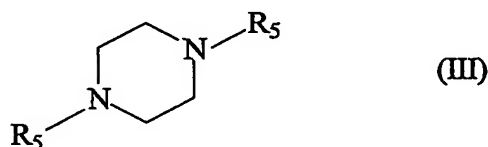
b) at least one alkanolamine compound of the formula



or

at least one piperazine compound of formula

10



15

wherein  $R_3$  is hydrogen, an alkyl group having from 1 to 6 carbon atoms, or the  $R_4OH$  group;  $R_4$  is a branched or unbranched alkylene group having from 1 to 6 carbon atoms;  $R_5$ , independently in each occurrence, is hydrogen or an hydroxyalkyl group having from 1 to 4 carbon atoms; and  $R_6$  is hydrogen, an alkyl group having from 1 to 6 carbon atoms or an hydroxyalkyl group having from 1 to 4 carbon atoms.

20

In another aspect, the present invention concerns a process for selective removal of COS from a gas stream containing same, said process comprising treating the gas stream with a solvent composition comprising

a) at least one polyalkylene glycol alkyl ether of the formula



wherein  $R_1$  is an alkyl group having from 1 to 6 carbon atoms;  $R_2$  is hydrogen or an alkyl group having from 1 to 4 carbon atoms; Alk is an alkylene group, branched or unbranched, having from 2 to 4 carbon atoms; and  $n$  is from 1 to 10; and

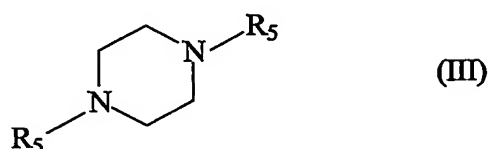
b) at least one alkanolamine compound of the formula



5

or

at least one piperazine compound of formula



10

wherein  $R_3$  is hydrogen, an alkyl group having from 1 to 6 carbon atoms, or the  $R_4OH$  group;  $R_4$  is a branched or unbranched alkylene group having from 1 to 6 carbon atoms;  $R_5$ , independently in each occurrence, is hydrogen or an hydroxyalkyl group having from 1 to 4 carbon atoms; and  $R_6$  is hydrogen, an alkyl group having from 1 to 6 carbon atoms or an hydroxyalkyl group having from 1 to 4 carbon atoms.

15

Still in another aspect, the present invention concerns a process for selective removal of COS from a gas stream containing same, said process comprising treating the gas stream with a solvent composition comprising

20

a) 1,3-dimethyl-3,4,5,6-tetrahydro-2(1H)-pyrimidinone; and

b) at least one alkanolamine compound of the formula

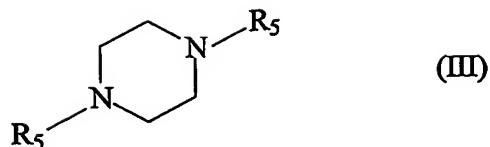
25



or

at least one piperazine compound of formula





wherein  $R_3$  is hydrogen, an alkyl group having from 1 to 6 carbon atoms, or the  
 5  $R_4OH$  group;  $R_4$  is a branched or unbranched alkylene group having from 1 to 6  
 carbon atoms;  $R_5$ , independently in each occurrence, is hydrogen or an hydroxyalkyl  
 group having from 1 to 4 carbon atoms; and  $R_6$  is hydrogen, an alkyl group having  
 from 1 to 6 carbon atoms or an hydroxyalkyl group having from 1 to 4 carbon atoms.

10 Still in another aspect, the present invention concerns a solvent composition for  
 removal of COS from a gas stream containing same, said composition comprising

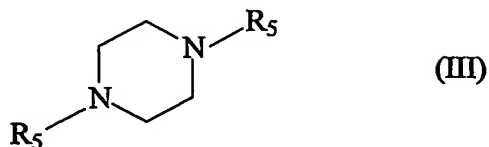
a) a mixture of N-formylmorpholine and N-acetylmorpholine; and

15 b) at least one alkanolamine compound of the formula



or

at least one piperazine compound of formula



wherein  $R_3$  is hydrogen, an alkyl group having from 1 to 6 carbon atoms, or the  $R_4OH$  group;  $R_4$  is a branched or unbranched alkylene group having from 1 to 6 carbon atoms;  $R_5$ , independently in each occurrence, is hydrogen or an hydroxyalkyl group having from 1 to 4 carbon atoms; and  $R_6$  is hydrogen, an alkyl group having from 1 to 6 carbon atoms or an hydroxyalkyl group having from 1 to 4 carbon atoms.

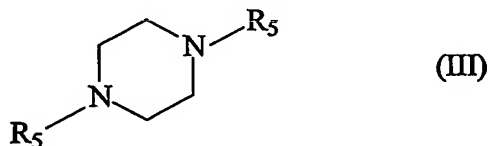
Still in another aspect, the present invention concerns a process for selective removal of COS from a gas stream containing same, said process comprising treating the gas stream with a solvent composition comprising

- a) a mixture of N-formylmorpholine and N-acetylmorpholine; and
- b) at least one alkanolamine compound of the formula



or

at least one piperazine compound of formula



wherein  $R_3$  is hydrogen, an alkyl group having from 1 to 6 carbon atoms, or the  $R_4OH$  group;  $R_4$  is a branched or unbranched alkylene group having from 1 to 6 carbon atoms;  $R_5$ , independently in each occurrence, is hydrogen or an hydroxyalkyl group having from 1 to 4 carbon atoms; and  $R_6$  is hydrogen, an alkyl group having from 1 to 6 carbon atoms or an hydroxyalkyl group having from 1 to 4 carbon atoms.

As used herein, the terms "gas", "acid gas", and "gaseous stream" are intended to refer to natural gas, hydrocarbon gas, synthesis gas, steam reformer-type gases, and any other gas containing COS,  $CO_2$  and other gaseous components such as hydrogen sulfide, methane, ethane, propane, hydrogen, carbon monoxide, mercaptans etc. The expression "minimal additional removal of  $CO_2$ " means additional  $CO_2$  absorption due to the presence of the amine additive is less than one third of the  $CO_2$  present in the feed gas, all other factors being the same.

In accordance with the present invention, it has been surprisingly discovered that the solvent compositions of the present invention have excellent selectivity for the removal of COS from a gaseous stream containing same with minimal additional removal of  $CO_2$ .

It was completely surprising and unexpected to find out addition of an alkanolamine compound of formula II above or a piperazine compound of formula III above to least one polyalkylene glycol alkyl ether of the formula I above, and in particular to a mixture of polyalkylene glycol ethers of formula I above, such as the SELEXOL<sup>TM</sup> solvent, removes substantially more of the COS present in the gaseous streams with minimal additional removal of  $CO_2$ .

It was also equally surprising and unexpected to find out that the addition of an alkanolamine compound of formula II above or a piperazine compound of formula III above to 1,3-dimethyl-3,4,5,6-tetrahydro-2(1H)-pyrimidinone removes substantially more of COS present in the gaseous streams with minimal additional removal of  $CO_2$

Polyalkylene alkyl ethers of formula I suitable in the practice of the present invention are well known and include, without any limitation, diethylene glycol dimethyl ether, diethylene glycol diisopropyl ether, triethylene glycol dimethyl ether, triethylene glycol diisopropyl ether, tetraethylene glycol dimethyl ether, tetraethylene glycol diisopropyl ether, pentaethylene glycol dimethyl ether, pentaethylene glycol diisopropyl ether, hexaethylene glycol dimethyl ether, hexaethylene glycol diisopropyl ether, heptaethylene glycol dimethyl ether, octaethylene glycol dimethyl ether, nonaethylene glycol dimethyl ether, decaethylene glycol dimethyl ether, and any mixture thereof.

Preferred polyethylene glycol alkyl ether is a mixture consisting of a dimethyl ethers of polyethylene glycols of formula  $\text{CH}_3\text{O}(\text{C}_2\text{H}_4\text{O})_n\text{CH}_3$  wherein n is from 2 to 10.. Particularly preferred polyethylene glycol alkyl ether is the mixture of dimethyl ethers of polyethylene glycols sold under the trademark SELEXOL by Union Carbide Corporation. SELEXOL<sup>TM</sup> solvent is a mixture of dimethyl ethers of polyethylene glycols comprising from 0 to 0.5 wt percent of diethylene glycol dimethyl ether, from 5 to 7 wt percent of triethylene glycol dimethyl ether, from 16 to 18 wt percent tetraethylene glycol dimethyl ether, from 23 to 25 wt percent of pentethylene glycol dimethyl ether, from 22 to 24 wt percent of hexaethylene glycol dimethyl ether, from 15 to 17 wt percent of heptaethylene glycol dimethyl ether, from 8 to 10 wt percent of octaethylene glycol dimethyl ether, from 3 to 5 wt percent of nonaethylene glycol dimethyl ether, and from 1 to 2 wt percent of decaethylene glycol dimethyl ether. SELEXOL<sup>TM</sup> solvent is widely used in gas treating applications for the removal of acidic gases. However, it is known that the removal of COS by the SELEXOL<sup>TM</sup> solvent is poor due to solvent factors (low solubility) and applications specific factors (low COS partial pressure). Certain amine additives such as bicyclic tertiary amines and tertiary amines have been used, with some success, to improve removal of COS by SELEXOL<sup>TM</sup> solvent. It has now been discovered that the SELEXOL<sup>TM</sup> solvent containing alkanolamines of formula II hereinbefore or a piperazine compound of formula III hereinabove is surprisingly selective in removing COS in the presence of CO<sub>2</sub> from gases.

Alkanolamine compounds of formula II usefull in the practice of the present invention are well known compounds and include both primary and secondary alkanolamines. Preferred alkanolamine compounds of formula II are primary

alkanolamines. Non-limiting examples of alkanolamine compounds are monoethanolamine (MEA), diethanolamine (DEA), methylethanolamine (NMEA), diisopropanolamine (DIPA), and 2-(2-aminoethoxy)ethanol (AEE) also known as diethylene glycolamine (available from Huntsman Corporation under the trademark DGA).

5

The present invention is particularly useful in the desulfurization portion of an Integrated Combined Cycle Gasification (IGCC) process using an IGCC system consisting of a conventional SELEXOL<sup>TM</sup> solvent acid gas removal unit, a fixed bed catalytic converter for reducing the gas phase concentration of carbonyl sulfide (COS), and heat  
10 exchanger equipment upstream of the SELEXOL<sup>TM</sup> solvent unit. It has been surprisingly found out that the addition of the alkanolamine compound of formula II above to the SELEXOL<sup>TM</sup> solvent results in selective removal of COS from the gas feed in the presence of CO<sub>2</sub> with minimal removal of CO<sub>2</sub>. The costs associated with the fixed bed catalytic converter are also significantly reduced.

15

Since the process of the present invention for selective removal of COS from gaseous streams is conducted in the desulfurization portion of an Integrated Combined Cycle Gasification (IGCC) process, the operating conditions of the process are those of the IGCC process. These operating conditions are well known to a person of an ordinary skill  
20 in the art.

All parts, percentages and ratios herein are by weight unless otherwise indicated.

The invention will be further clarified by a consideration of the following examples  
25 that are intended to be purely exemplary of the present invention and not limiting in any way.

The following components are employed in the examples.

30

MEA is monoethanolamine;

DEA is diethanolamine;

TEA is triethanolamine;

NMEA is methylethanoamine;

DIPA is diisopropanolamine;

HEP is hydroxyethylpiperazine;

MDEA is methyldiethanolamine;

DMEA is dimethylethanolamine;

5 DBU is 1,8-diazabicyclo[5.4.0]undec-7-ene;

DBN is 1,5-diazabicyclo[4.3.0]non-5-ene;

DABCO is 1,4-diazabicyclo[2.2.2]octane, sold by Air Products and Chemicals, Inc. under the trademark DABCO;

DMTP is 1,3-dimethyl-3,4,5,6-tetrahydro-2(1H)-pyrimidinone;

10 Quinuclidine is 1,4-ethanolpiperidine; and

AEE is 2-(2-aminoethoxy)ethanol.

#### Examples 1 to 10 and Comparative Examples 1 to 12

15 The performance of SELEXOL<sup>TM</sup> solvent alone, and the mixture of SELEXOL<sup>TM</sup> solvent and prior art additives were evaluated in a bench scale glass absorber-stripper apparatus with the following characteristics:

- 20 a) standard gas feed conditions (10 mole percent CO<sub>2</sub>, 1.6 mole percent COS, and the balance nitrogen, about 3 L/min, 80 °F),
- b) standard liquid feed conditions (about 11 cc/min, 80 °F),
- c) standard amount of absorber and stripper staging (small trays, 25 absorber, 20 stripper),
- d) approximately standard amount of stripping heat duty applied,
- 25 e) standard amount of the additive used about 3 percent by weight),
- f) gas phase analysis by gas chromatography, liquid phase water content by Karl Fisher method,
- g) careful attention to ensuring steady state operation,
- h) liquid phase COS content was not measured, and
- 30 i) stripper overhead not sampled for COS or H<sub>2</sub>S.

The results obtained in the performance evaluation of different gas treating solvent are provided in Tables below.

**Table 1**

Evaluation of Prior Art and Various Additives for Removal of COS by SELEXOL™ solvent

5

Solvent	COS Absorption (percent of feed)	CO <sub>2</sub> Absorption (percent of feed)
SELEXOL™ solvent*	0.7	0.7
SELEXOL™ solvent*	1.2	0.2
S+3 wt percent 1,4 diazabicyclo[2.2.2]octane (DABCO)*	2.6	0.0
S+3 wt percent quinuclidine*	5.1	-0.2
S+3 wt percent 1,5-diazabicyclo[4.3.0]non-5-ene (DBN)*	3.1	-0.6
S+3 wt percent 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU)*	2.5	0.5
S+3 wt percent triethanolamine (TEA)*	2.0	0.5
S+3 wt percent triethanolamine (TEA)*	-0.7	2.7
S+3 wt percent methyldiethanolamine (MDEA)*	1.3	1.3
S+3 wt percent dimethylethanolamine (MDEA)*	2.0	0.0
S+3 wt percent hydroxyethylpiperazine (HEP)	17.1	0.7
S+3 wt percent diisopropanolamine (DIPA)	18.9	1.0
S+3 wt percent diethanolamine (DEA)	18.9	2.8
S+3 wt percent diethanolamine (DEA)	28.3	0.1
S+3 wt percent monoethanolamine (MEA)	28.3	-0.7
S+3 wt percent piperazine	29.1	0.8
S+3 wt percent methylethanolamine (NMEA) **	6.6	-0.6
S+3 wt percent methylethanolamine (NMEA)	52.1	0.9
S+3 wt percent methylethanolamine (NMEA)	50.3	1.1
DMTP*	5.8	-1.0
DMTP*	3.6	-1.1
DMTP +3 wt percent diethanolamine	40.1	0.6

\* not an Example of the present invention

\*\* spurious experimental outcome

S = SELEXOL™ solvent

10

(continued on the next page)

Table 2

	Comparative Example 1	Example 1	Example 2	Comparative Example 2	Comparative Example 3
Base Solvent	SELEXOL™ Solvent	SELEXOL™ Solvent	SELEXOL™ solvent	DMTP	SELEXOL™ solvent
Additive	0	Piperazine	NMEA	none	DBU
Additive Concentration (wt percent)	25	3	3	0	3
# Absorber Trays	20	25	25	25	25
# Stripper Trays		20	20	20	20
Total Gas Feed Rate (cc/min)	2997	2996	2995	3026	3008
Feed CO <sub>2</sub> (mole percent)	10.09	10.18	10.06	9.64	11.06
Feed COS (mole percent)	1.48	1.51	1.51	1.21	1.63
Sweet CO <sub>2</sub> (mole percent)	10.02	10.1	10.12	9.74	11.01
Sweet COS (mole percent)	1.47	1.07	1.41	1.14	1.59
Absorber:					
Lean H <sub>2</sub> O content (wt percent)	3.2	4	4.6	7.4	4.3
Lean Solvent Flow (cc/min)	11	11	11	11	11
Lean T (F)	80.7	78.8	79.8	79.8	80.5
Feed Gas T (F)	80.8	79.1	79.5	79.3	80.3
Sweet Gas T (F)	81.6	79.5	80.6	79.8	80.8
Rich T (F)	79.3	77.6	78.1	77.9	77.1
Absorber P (in H <sub>2</sub> O)	28	28	28	28	28
Stripper:					
Hot Rich Inlet T (F)	239.1	220.3	232.5	229.1	231.5
Overhead Vap T (C)	103	100	103	100	100
Reboiler T (F)	264.7	258.3	254.6	270.5	259.5
COS Absorption (percent of feed)	0.7	29.1	6.6	5.8	2.5
CO <sub>2</sub> Absorption (percent of feed)	0.7	0.8	-0.6	-1.0	0.5

5

(continued on the next page)



**Table 3**

	Comparative Example 4	Comparative Example 5	Example 3
Base Solvent	SELEXOL™ Solvent	SELEXOL™ Solvent	SELEXOL™ solvent
Additive	DBN	DABCO	DEA
Additive Concentration (wt percent)	3	3	3
Number of Absorber Trays	25	25	25
Number of Stripper Trays	20	20	20
Total Gas Feed Rate (cc/min)	3000	2999	3004
Feed CO <sub>2</sub> (mole percent)	10.9	10.26	10.3
Feed COS (mole percent)	1.6	1.51	1.48
Sweet CO <sub>2</sub> (mole percent)	10.97	10.26	10.01
Sweet COS (mole percent)	1.55	1.47	1.2
Absorber:			
Lean H <sub>2</sub> O content (wt percent)	4	3.6	4.1
Lean Solvent Flow (cc/min)	11	11	11
Lean T (F)	80.7	82.3	81.1
Feed Gas T (F)	80.3	81.8	81
Sweet Gas T (F)	80.8	82.3	81.6
Rich T (F)	79.4	79.5	79.8
Absorber P (in H <sub>2</sub> O)	28	28	28
Stripper:			
Hot Rich Inlet T (F)	227.6	246.5	226.7
Overhead Vap T (C)	100	102	102
Reboiler T (F)	259.9	260.6	256.1
COS Absorption (percent of feed)	3.1	2.6	18.9
CO <sub>2</sub> Absorption (percent of feed)	-0.6	0.0	2.8

5

(continued on the next page)

Table 4

	Example 4	Comparative Example 6	Comparative Example 7	Example 5	Example 6
Base Solvent	SELEXOL™ Solvent	SELEXOL™ solvent	SELEXOL™ solvent	SELEXOL™ solvent	SELEXOL™ solvent
Additive	MEA	Quinuclidine	none	DEA	NMEA
Additive Concentration (wt percent)	3	3	0	3	3
Number of Absorber Trays	25	25	25	25	25
Number of Stripper Trays	20	20	20	20	20
Total Gas Feed Rate (cc/min)	2999	2978	2985	2990	3012
Feed CO <sub>2</sub> (mole percent)	10.09	10.06	10.13	10.03	10.11
Feed COS (mole percent)	1.8	1.76	1.72	1.7	1.67
Sweet CO <sub>2</sub> (mole percent)	10.16	10.08	10.11	10.02	10.02
Sweet COS (mole percent)	1.29	1.67	1.7	1.43	0.8
Absorber:					
Lean H <sub>2</sub> O content (wt percent)	5.4	4.5	3.7	3.6	4
Lean Solvent Flow (cc/min)	11	11	11	11	11
Lean T (F)	79.7	80.7	82	83.2	80.9
Feed Gas T (F)	80.6	79.9	80.5	81.8	83.2
Sweet Gas T (F)	81.1	81	81.4	83	83.5
Rich T (F)	78.6	76.7	77.8	80.9	82.5
Absorber P (in H <sub>2</sub> O)	28	28	28	28	28
Stripper:					
Hot Rich Inlet T (F)	222.1	213.8	209.7	207.6	201.2
Overhead Vap T (C)	109	103	105	101	100
Reboiler T (F)	246.6	250.2	257.5	256.9	255.1
COS Absorption (percent of feed)	28.3	5.1	1.2	15.9	52.1
CO <sub>2</sub> Absorption (percent of feed)	-0.7	-0.2	0.2	0.1	0.9

5

(continued on the next page)

Table 5

	Example 7	Example 8	Comparative Example 89	Example 98	Comparative Example 9
Base Solvent	SELEXOL™ Solvent	SELEXOL™ Solvent	DMTP	SELEXOL™ Solvent	SELEXOL™ solvent
Additive	NMEA	DIPA	none	HEP	TEA
Additive Concentration (wt percent)	3	3	0	3	3
Number of Absorber Trays	25	25	25	25	25
Number of Stripper Trays	20	20	20	20	20
Total Gas Feed Rate (cc/min)	3023	3013	3004	2990	3000
Feed CO <sub>2</sub> (mole percent)	10.08	10.08	10.02	10.06	10.01
Feed COS (mole percent)	1.61	1.64	1.67	1.58	1.52
Sweet CO <sub>2</sub> (mole percent)	9.97	9.98	10.13	9.99	9.96
Sweet COS (mole percent)	0.8	1.33	1.61	1.31	1.49
Absorber:					
Lean H <sub>2</sub> O content (wt percent)	3.7	4	8.2	3.2	3.6
Lean Solvent Flow (cc/min)	11	11	11	11	11
Lean T (F)	79.4	82.9	82.4	84.2	81
Feed Gas T (F)	78.4	81.3	81.1	82.4	79.3
Sweet Gas T (F)	79.4	82.6	82	83.7	80.3
Rich T (F)	78.3	80.1	79.6	80.2	77.5
Absorber P (in H <sub>2</sub> O)	28	28	28	28	28
Stripper:					
Hot Rich Inlet T (F)	200.2	206.7	198.9	197.5	180.5
Overhead Vap T (C)	101	100	104	100	101
Reboiler T (F)	255.6	255.6	271.3	258.4	255.7
COS Absorption (percent of feed)	50.3	18.9	3.6	17.1	2.0
CO <sub>2</sub> Absorption (percent of feed)	1.1	1.0	-1.1	0.7	0.5

5

(continued on the next page)

Table 6

	Comparative Example 10	Comparative Example 11	Example 10	Comparative Example 12
Base Solvent	SELEXOL™ Solvent	SELEXOL™ Solvent	DMTP	SELEXOL™ solvent
Additive	TEA	MDEA	DEA	DMEA
Additive Concentration (wt percent)	3	3	3	3
Number of Absorber Trays	25	25	25	25
Number of Stripper Trays	20	20	20	20
Total Gas Feed Rate (cc/min)	3005	2995	2981	2994
Feed CO <sub>2</sub> (mole percent)	10.17	10.01	10.09	9.95
Feed COS (mole percent)	1.48	1.52	1.52	1.47
Sweet CO <sub>2</sub> (mole percent)	9.9	9.88	10.03	9.95
Sweet COS (mole percent)	1.49	1.5	0.91	1.44
Absorber:				
Lean H <sub>2</sub> O content (wt percent)	4.2	3.8	8.6	4
Lean Solvent Flow (cc/min)	11	11	11	11
Lean T (F)	82.6	82.6	80	80.3
Feed Gas T (F)	80.4	80.4	79	79.7
Sweet Gas T (F)	81.9	81.8	79.6	81
Rich T (F)	77.8	78.5	79.4	76.9
Absorber P (in H <sub>2</sub> O)	28	28	28	28
Stripper:				
Hot Rich Inlet T (F)	185.2	189.5	182.2	198.3
Overhead Vap T (C)	102	108	105	108
Reboiler T (F)	256.6	257.6	264.3	253.7
COS Absorption (percent of feed)	-0.7	1.3	40.1	2.0
CO <sub>2</sub> Absorption (percent of feed)	2.7	1.3	0.6	0.0

5

As can be seen from the Tables 1-6 hereinabove, certain amine additives of the prior art improve removal of COS without substantially increasing the removal of CO<sub>2</sub>. For example, the addition of DABCO, quinuclidine, DBN and DBU to the SELEXOL™ solvent increases the COS removal of to the SELEXOL™ solvent from 1 percent to 2-5 percent.

10

Examples 11 to Example 15 and Comparative Examples 13 to 14

The performance of a physical solvent alone, and the mixture of the physical solvent and prior art additives of the present invention were evaluated in a bench scale glass

5 absorber-stripper apparatus with the following characteristics:

- j) standard gas feed conditions (8.7-10 mole percent CO<sub>2</sub>, 1.1-1.5 mole percent COS, and the balance nitrogen, about 3 L/min),
- k) standard liquid feed conditions (about 11 or 30 cc/min),
- 10 l) standard amount of absorber and stripper staging (small trays, 25 absorber, 20 stripper),
- m) approximately standard amount of stripping heat duty applied,
- n) standard amount of the additive used about 3 percent by weight),
- o) gas phase analysis by gas chromatography, liquid phase water content by
- 15 Karl Fisher method,
- p) careful attention to ensuring steady state operation,
- q) liquid phase COS content was not measured, and
- r) stripper overhead not sampled for COS or H<sub>2</sub>S.

20 The results obtained in the performance evaluation of different gas treating solvent are provided in Tables 7 and 8 below.

(continued on the next page)

Table 7

	Comparative Example 13	Example 11	Example 12	Example 13
			003	
Base Solvent	SELEXOL™	SELEXOL™	SELEXOL™ <sub>M</sub>	SELEXOL™
Additive	None	HEP	HEP	AEE
Additive Concentration (wt percent)	0	3	3	3
# Absorber Trays	25	25	25	25
# Stripper Trays	20	20	20	20
Total Gas Feed Rate (cc/min)	2985	2985	2985	2985
Feed CO <sub>2</sub> (mole percent)	8.65	9.34	9.76	9.75
Feed COS (mole percent)	1.48	1.47	1.44	1.43
Sweet CO <sub>2</sub> (mole percent)	8.65	8.14	8.61	8.36
Sweet COS (mole percent)	1.33	0.52	0.58	0.41
Absorber:				
Lean H <sub>2</sub> O content (wt percent)	7.2	3.9	6.8	3.9
Lean Solvent Flow (cc/min)	30	30	30	30
Lean T (F)	81	85	84	85
Feed Gas T (F) <sup>1</sup>	89	89	89	89
Sweet Gas T (F)	66	72	72	70
Rich T (F) <sup>2</sup>	83	88	88	87
Absorber P (in H <sub>2</sub> O)	28	28	28	28
Stripper:				
Hot Rich Inlet T (F)	209	203	194	204
Overhead Vapor T (F)	215	216	215	214
Reboiler T (C)	115	122	118	132
COS Absorption (percent of feed)	10	65	60	71
CO <sub>2</sub> Absorption (percent of feed)	0	13	12	14

- 5 1 measured at outlet of feed gas heater  
2 measured in pot beneath lowest absorber tray

As can be seen from the Table 7 hereinabove, the SELEXOL™ solvent alone removes about 10 percent of the COS from the feed gas while the addition of about 3 wt percent of HEP or AEE to the SELEXOL™ solvent improves COS removal to 60-70 percent. Removal of CO<sub>2</sub> increases from 0 to 12-14 percent.

(continued on the next page)

Table 8

	Comparative Example 14	Example 14	Example 15
Base Solvent	DMTP	DMTP	DMTP
Additive	none	HEP	NMEA
Additive Concentration (wt percent)	0	3	3
# Absorber Trays	25	25	25
# Stripper Trays	20	20	20
Total Gas Feed Rate (cc/min)	2985	2985	2985
Feed CO <sub>2</sub> (mole percent)	9.75	9.73	9.66
Feed COS (mole percent)	1.43	1.43	1.42
Sweet CO <sub>2</sub> (mole percent)	9.47	9.14	8.69
Sweet COS (mole percent)	1.31	0.45	0.0
Absorber:			
Lean H <sub>2</sub> O content (wt percent)	9.1	4.9	3.9
Lean Solvent Flow (cc/min)	11	11	11
Lean T (F)	76	79	82
Feed Gas T (F) <sup>1</sup>	85	84	77
Sweet Gas T (F)	71	72	68
Rich T (F) <sup>2</sup>	82	83	82
Absorber P (in H <sub>2</sub> O)	28	28	28
Stripper:			
Hot Rich Inlet T (F)	238	261	244
Overhead Vapor T (F)	216	212	211
Reboiler T (C)	129	149	150
COS Absorption (percent of feed)	8	69	100
CO <sub>2</sub> Absorption (percent of feed)	3	6	10

5

1 measured at outlet of feed gas heater

2 measured in pot beneath lowest absorber tray

As can be seen from the Table 8 hereinabove, DMTP solvent alone removes about 8 percent of the COS from the feed gas while the addition of about 3 wt percent of HEP or NMEA to the DMTP solvent improves COS removal to about 69-100 percent. Removal of CO<sub>2</sub> increases from 3 to 6-10 percent.

As can also be seen from the Tables 1-8 hereinabove, all the solvent compositions of the present invention showed a marked improvement in COS removal with minimal additional CO<sub>2</sub> removal. Overall, the solvent compositions of the present invention comprising the SELEXOL<sup>TM</sup> solvent and the alkanolamine of formula II or piparazine compound of formula III removed COS in an amount of from 17 percent to 52 percent as

compared to the SELEXOL<sup>TM</sup> solvent alone which removed COS in an amount of only about 1 percent. Similarly, the solvent composition of the present invention comprising DMTP and the alkanolamine of formula II removed COS in an amount of 40 - 100 percent as compared to DMTP alone which removed COS in an amount of from 3 - 8 percent. Such  
5 magnitude of improved removal of COS by the solvent compositions of the present invention is completely unexpected and unpredictable.

Other embodiments of the invention will be apparent to those skilled in the art from a consideration of this specification or practice of the invention disclosed herein. It is  
10 intended that the specification and examples be considered as exemplary only, with the true scope and spirit of the invention being indicated by the following claims.